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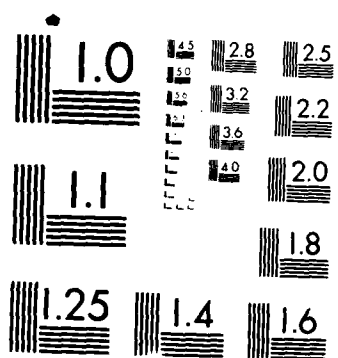
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COMPLETED RIW CONTRACTS

THESIS

Paul E. Leix  
Captain, USAF

AFIT/GLM/LSQ/85S-43

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COST/BENEFIT ANALYSIS OF COMPLETED RIW CONTRACTS

THESIS

Presented to the Faculty of the School of Systems and Logistics  
of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the  
Requirements for the Degree of  
Master of Science in Logistics Management

Paul E. Leix, B.A.

Captain, USAF

September 1985

Approved for public release; distribution unlimited

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Paul E. Leix

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Abstract

Reliability Improvement Warranties (RIWs) were implemented by the Air Force in 1974. This marked the beginning of the eight-year RIW trial period. Six major Air Force programs have used RIWs since 1974. The Air Force Director of Contracting and Manufacturing Policy requested that the RIW trial period be ended and that the effectiveness of this program during the trial period be measured. This research project was an attempt to evaluate the costs and benefits associated with two RIWs implemented during this time period. Reliability data and maintenance man-hour values were collected on warranted equipment throughout its history of operation. Similar data was collected on equivalent non-warranted equipment for comparison purposes. The increase in reliability and decrease in expended maintenance man-hours on warranted equipment was also compared to the increase in contract costs associated with the RIW. This study indicated that the RIW was a cost-effective tool in increasing reliability and reducing the number of man-hours required to maintain certain Air Force equipment.

## COST/BENEFIT ANALYSIS OF COMPLETED RIW CONTRACTS

### I. The Research Problem

#### Introduction

The Department of Defense (DOD) is currently faced with the problem of attempting to procure the complex equipment needed for defense within the limits of ever-tightening budget constraints. The constant decrease in the real purchasing power of the defense dollar has resulted in a continuing search for ways to reduce the cost of maintaining the defense establishment. A dilemma which the defense manager thus faces is how to maintain the current level of defense, and at the same time obtain funds to purchase equipment designed for increased reliability and maintainability. One of the devices aimed at improving reliability of weapon systems and reducing their life-cycle costs now being used by the DOD is the Reliability Improvement Warranty (RIW).

#### Background

In 1964, Air Force Operational and Maintenance (O&M) costs accounted for 21 percent of the Air Force budget; and in 1973, O&M costs were responsible for 27 percent of the Air Force budget (5:6). With Air Force O&M costs rising and defense budget constrained, it was clear that operation and logistics support costs must be curtailed. There also was a concern at all levels about U.S. military readiness. This

concern stemmed, in part, from the heavy emphasis placed by the services on performance, often to the detriment of reliability and maintainability. However, prompted by expressed administration policies, DOD has gradually accentuated the issue of supportability since the early 1970's, thus requiring the services to reassess their priorities (9:130).

In August 1973, the Assistant Secretary of Defense (Installations and Logistics) directed the trial use of warranties by the services in the acquisition and initial operational support of a number of electronic subsystems. In response to this Department of Defense (DOD) direction, the Directorate of Procurement Policy, Headquarters USAF, published the "Interim Reliability Improvement Warranty (RIW) Guidelines" in July 1974.

Under RIW, a contractor assumes responsibility on a fixed-price basis for repairing or replacing warranted units that fail during the warranty period. The price of the reliability improvement warranty is negotiated based on the projection of field reliability together with a projection of average repair costs. The contractor can achieve a higher profit by developing a system that exhibits a higher field reliability. The concept of an RIW is innovative in the sense that, rather than being indifferent to field-experienced failures, the contractor now has a financial incentive to limit the number of field failures because the cost of their repair is taken from the original payment for the warranty contract (9:137).

### Problem Statement

For the government to introduce these types of incentives, hardware acquisition costs as well as administrative complexity are increased under the concept. As a result, DOD must determine whether the RIW concept is cost effective, especially with electronic navigational equipment purchased by the DOD. So far DOD has not completely evaluated the effectiveness of all the completed RIW programs.

### Review of the Literature

The airlines use a concept of form, fit, and function interchangeability for much of their avionics equipment. Since the 1930s, this has been part of the commercial airline acquisition methodology (CAAM), a primary feature of which uses warranty clauses in acquisition contracts (8:16). Pan American Airlines, Inc., with over \$1 billion invested in 747 aircraft, wanted to reduce the high support cost risks associated with poor equipment reliability in their aircraft fleet (8:11). In doing so, Pan American specified a guaranteed mean-time-between-failure (MTBF) which would be achieved by the end of the five-year warranty period (8:12). As a result of this airline experience, Aeronautical Radio, Incorporated (ARINC), the communications advisory board of the U.S. Air Transport Industry, developed a list of CAAM guidelines which form the present basis of the DOD RIW guidelines.

In general, an RIW will repair or replace failed units as well as provide agreed-to "no cost" engineering changes.

During the warranty period, the contractor will have an incentive to improve the reliability and to reduce the repair cost of the equipment through the mechanism of "no cost" engineering change proposals. Once a fixed price is established for the warranty, the actual profit realized by the contractor depends upon the equipment's reliability and maintainability in the field. His profit also depends on any improvements that he can make in its reliability and maintainability in order to keep the number and cost of repairs as low as possible. Thus, an RIW becomes a contracting technique by which the government derives the benefits of improved reliability and maintainability for each additional dollar that the contractor earns (9:139).

Warranties and various kinds of performance guarantees are valuable techniques frequently used in the acquisition process, but they are not appropriate in all cases. Although reliability improvement warranties have helped achieve reliability goals, tradeoffs are involved. For the contractor, there is pricing risk because of competitive pressures, optimistic reliability and maintainability estimates, unforeseen operational stresses, and mishandling that may occur in the field (4:26). The Air Force guidelines published in 1974 contained a section pertaining to RIW application criteria. The following criteria are used for selecting equipment as potential candidates for Reliability Improvement Warranty coverage:

(a) A warranty can be obtained at the price commensurate with the contemplated value of the warranty work to be accomplished.

(b) Moderate to high initial support costs are involved.

(c) The equipment is readily transportable to permit return to the vendor's plant or, alternatively, the equipment is one for which a contractor can provide service.

(d) The equipment is generally self-contained, is generally immune from failures induced by outside units, and has readily identifiable failure characteristics.

(e) The equipment application, in terms of expected operating time and the use environment, is known.

(f) The equipment is susceptible to being contracted for on a fixed price basis.

(g) The contract can be structured to provide a warranty period of several years. This should allow the contractor sufficient time to identify and analyze failures in order to permit reliability and maintainability improvements.

(h) The equipment has a potential for both reliability growth and reduction repair costs.

(i) Potential contractors indicate a comparative attitude toward acceptance of an RIW provision and evaluation of its effectiveness.

(j) A sufficient quantity of the equipment is to be procured in order to make the RIW cost effective.

(k) The equipment is of a configuration that discourages unauthorized field repair, preferably sealed and capable of containing an Elapsed Time Indicator (ETI) or some other means of usage control.

(l) There is a reasonable degree of assurance that there will be a high utilization of the equipment.

(m) The equipment is one that permits the contractor to effect no-cost engineering change proposals subsequent to the Government's approval.

(n) Failure data and the intended operational use data can be furnished the contractor for the proposed contractual period and updated periodically during the term of the contract (12:9).



The Air Force acquisition programs participated in the RIW trial period because they met most of the major criteria established for warranty application. These programs are listed in Table I below, along with the warranty period and RIW cost expressed as a percent of each unit's cost.

These programs have met with varying degrees of success in meeting their respective reliability goals. For example, the Air Force has exercised two of the three AN/ARN-118 TACAN production options and the reliability continues to increase. With over 3,000 TACAN sets delivered, the mean-time between-failure of the AN/ARN-118 TACAN is in excess of 1,700 hours, far beyond the required 1,000 hours MTBF (6:30).

In 1966, the F-111 Aircraft System Project Office and the Aeronautical Systems Division (ASD) Deputy for Subsystems, Compass and Reference System Section initiated an effort to determine the best plan for additional procurement of the attitude and heading reference system (AHRS) for the F/FB-111 aircraft. Previously, the reference system had been obtained from General Electric on a sole-source negotiated basis. As part of the planning effort, it was decided to hold a competition and to include a long-term warranty provision on the gyro unit contained in the AHRS.

A request for proposal was issued to 25 contractors but only General Electric and Lear Siegler Incorporated (LSI) responded. The resultant contract was awarded to LSI for 126 units, with delivery starting in May 1972. The warranty

TABLE I  
AIR FORCE RIW TRIAL PROGRAMS

PROGRAM	RIW START	RIW END	RIW COST PERCENT OF UNIT COST
C-130 Hydraulic Pump	Mar 75	Mar 82	12.3%
F-111 Gyro	Jun 73	Jun 78	23.0%
AVU-8C/A Airspeed Indicator	Apr 76	Apr 81	9.7%
Klystron Tube	Sep 76	Sep 80	6.3%
C-141 Attitude and Heading Reference System	Mar 77	Mar 82	12.0%
ARN-118 TACAN Unit	Apr 77	Apr 82	15.0%
Carousel IV INU	Apr 77	Apr 81	8.0%
OMEGA Navigation System	Oct 77	Nov 82	25.5%
F-16 Avionics	Jan 79	Dec 83	10.8%
A-10 INU	Apr 81	Apr 86	26.0%

provision called for 3,000 hours or five years of use. During this time, the mean-time-between-failure of the gyro unit was reported to be 1160 hours compared to 860 hours for the General Electric equipment (11:9).

The contractor made ten reliability and maintainability (R&M) design changes in the gyro unit prior to and during production. These changes were directly attributable to the RIW provision. With those R&M improvements, it is believed that the RIW provided greater reliability than would have been obtained without the RIW.

There are a number of benefits to be realized through the RIW contracting procedure. The contractor assumes the responsibility for field reliability, life-cycle costs are emphasized to a larger extent, and the initial support investment required by the Department of Defense will be minimal. Also, the contractor will be more motivated to introduce changes to increase the equipment's mean-time-between-failure, resulting in reliability growth (8:10). Among the actions approved by Deputy Secretary of Defense Carlucci on April 30, 1981, was Initiative 16, "Contractor Incentives to Improve Reliability and Support," which mandated the acquisition strategies of major programs include incentive programs. These programs, such as RIW, were designed to encourage contractors to attain the DOD's new reliability and maintainability R&M goals, among which are a reduction in the maintenance manpower required and a lowering of the skill levels necessary to operate and service the weapon system (9:132). These R&M goals are echoed today in the United States Air Force R&M 2000 Action Plan. The R&M 2000 Action Plan suggests that one way these objectives can be accomplished is by

establishing and implementing an aggressive policy for the use of Product Performance Agreements (PPAs), improving warranty administration, and intensifying management review of PPAs to ensure contractor commitment and motivation (13:11).

The Assistant Secretary of the Air Force (Research, Development, and Logistics) has said:

Overall, we have noted reliability of equipment with RIW at or above predictions. It appears, from the limited number of engineering change proposals during the production and deployment period, that the desired reliability is inherent in the equipment designed during the development phase. We have witnessed an increased attention by the manufacturers of RIW items to production quality control, vendor control, and parts selection. This added attention has been cited by the manufacturers as a direct by-product of the RIW and a main factor in having deployed equipment achieve the inherent design reliability. Additionally by limiting repair of defective items to trained contractor technicians, and feeding back failure analysis to the repair and manufacturing process, any pattern of material workmanship deficiencies can be quickly corrected (1:1).

Although a number of the positive aspects of the RIW have been pointed out, there are also certain potential disadvantages or problems. The Acquisition Improvement Steering Group made the following observation:

Incentive approaches are difficult to structure and usually add complexity to the contracting process. There has been little technical analysis of the type of incentives that will work best in a given acquisition situation. Each service has identified a shortage of qualified personnel in this area.... Some incentives may require the contractor to perform maintenance in the field, or in place of Service depots. The Services generally do not favor such arrangements (3: Atch A).

Other possible problems associated with RIW are increased system acquisition costs from the contractor's expending additional effort to achieve good initial reliability. Also, the ability to respond quickly in emergency situations may be impaired (8:12). There is no uniform policy to determine whether in-house or contract support should be relied upon in the event of a national emergency.

Also, the potential for legal dispute is high, especially when defining a "failure." The contractor's primary obligation under an RIW is to repair items furnished under the contract that fail to meet the warranty. The definition of failure is therefore a crucial determinant of the contractor's required performance, since it essentially defines the circumstances under which the contractor is legally obligated to repair defective units. One of the key RIW factors that the government and its contractors must agree upon is the definition of a relevant failure. Many failures are not the fault of the contractor and cannot logically be his responsibility. A relevant failure definition may exclude any failure in the following categories: fire, explosion, submersion, mistreatment either accidental or purposeful, flood, aircraft crash, induced failures, enemy action, improper or insufficient packaging, or improper installation (2:12). This list appears to practically exclude all failures, but it merely highlights the importance of stating exactly what constitutes a relevant failure. Mistreatment and system-induced failures must be considered very carefully to avoid creating the possibility of constant haggling and lawsuits over warranty coverage. The accepted definition obligates the contractor to repair all relevant failures at no additional cost. The accepted definition is also used to compute mean-time-between-failure (MTFB) figures for contract compliance (7:17).

In a review of nine RIW contracts, ARINC Research Corporation found that the RIW helped achieve high reliabilities. The Reliability Improvement Warranties improved MTBF to an average of over 40 percent greater than expected (10: Inclosure 9). This means fewer repairs, fewer spares, less maintenance, and higher combat effectiveness. However, the cost benefits of a warranty application should be analyzed and relevant tradeoffs should be identified. Warranties work best in a competitive market and when selectively applied to specific subsystems. The key to implementing a successful RIW program is to tailor RIW requirements to the specific equipment.

#### Research Objectives

1. To determine if completed RIW contracts have been cost effective.
2. To determine if equipment purchased under RIW contracts has shown greater reliability over similar non-warranted equipment.

#### Research Questions

1. What is the additional contract cost of placing equipment under a reliability improvement warranty?
2. Has DOD equipment purchased under reliability improvement warranties shown an increase in field reliability?
3. Do the benefits of increased reliability, such as reduced maintenance man-hours, offset the increased

acquisition costs associated with a reliability improvement warranty?

### Research Report Overview

As an overview of this research report, the content of the remaining chapters is briefly discussed.

Chapter II describes the methodology used to accomplish the research objectives and answer the research questions discussed in Chapter I. This chapter describes the two acquisition programs selected for analysis in the research effort. This chapter also outlines the data collection and analysis plans, along with the assumptions and limitations of the research.

Chapter III contains the findings from the data analysis. These findings are summarized in tabular and graphical format to display the relative reliability and maintainability of the selected equipment.

Chapter IV summarizes the conclusions that can be drawn from this study of the effectiveness of the two selected Air Force RIW contracts during the past eight years. Recommendations for future research are suggested at the end of this chapter.

## II. Methodology

### Introduction

In chapter I, the basic problem and formulated research questions were defined. This chapter outlines the scope of the research and the methodology used in answering the research questions. This chapter also discusses data collection and analysis, assumptions, and limitations of this research effort.

### Scope of Research

From the ten Air Force acquisition programs participating in the RIW trial period starting in 1973, two were selected for this research analysis. The first program studied was the Carousel IV Inertial Navigation Unit (INU) installed on C-141 cargo aircraft under contract F09603-76-C-0361. In addition to performing primary navigation functions, the Carousel IV INU may also be utilized as a source for en route steering to the autopilot, for display of various navigation data on the flight, and provide attitude source information for the aircraft. Delco Electronics had been providing the Carousel INU to several commercial airline operators prior to the Air Force contract. The Air Force Carousel INU program was an off-the-shelf procurement of the commercial set with an RIW contract clause and a mean-time-between-failure (MTBF) guarantee. The first INU was installed in 1977 and the RIW expired in March 1981. A



total of 544 inertial navigation units were installed on C-141 aircraft over this time.

The Carousel IV RIW program was selected for this research because all required historical data was available. Both base level and depot level maintenance man-hour figures were readily accessible along with the associated failure data. Furthermore, the contract with the RIW line item and price was available for review along with the warranty effectiveness report.

The second program selected for analysis was the AN/ARN-118 Airborne Tactical Air Navigation (TACAN) receiver-transmitter unit (RTU) installed on F-15 fighter aircraft as part of contract F19628-75-C-0144. The AN/ARN-118 TACAN unit provides the aircraft pilot with bearing and slant range information in relation to a fixed ground station. It also transmits range information from other suitably equipped aircraft. To evaluate the benefits of the AN/ARN-118 TACAN RIW, a comparison was made with the AN/ARN-111 TACAN. The first 276 F-15 aircraft had been equipped with the AN/ARN-111 TACAN, a set of equivalent technology but procured without RIW. The remainder of the F-15 aircraft were equipped with the warranted AN/ARN-118, starting in 1978. The RIW expired in April 1982.

The AN/ARN-118 TACAN unit was selected for study because the failure and maintenance man-hour data was readily available from the historical files at the Air Force Logistics Command. The original contract, including the RIW

provision and price, and the warranty data and effectiveness reports were also available. In addition, the comparison of the two similar types of TACAN units during the same period on the same aircraft afforded a unique opportunity to gauge the benefits of the RIW concept.

#### Data Collection Plan

Data for RIW cost was collected by observation from contract files at the Product Performance Agreement Center in the Air Force Acquisition Logistics Center and Warner-Robins Air Logistics Center. Aircraft operational flight times and maintenance man-hour and failure data were obtained from the Maintenance Data Collection (MDC) system BO6 reports. The MDC system, established by Air Force Manual 66-1, "Maintenance Management," was designed primarily as a base-level maintenance management system for operational weapon systems and support equipment. The MDC system establishes a data base to provide information feedback to base managers and supervisors for controlling maintenance operations and to the USAF and its major commands for controlling maintenance programs. All base-level maintenance actions involving direct labor expenditure such as scheduled inspections, preventive maintenance, and unscheduled maintenance, both on-line and off-line, are reported in the MDC system. Each MDC BO6 report provides flight line and shop repair historical information on the maintenance actions, man-hours, by month, on every work unit code on an associated aircraft.

To determine the value of the maintenance man-hours expended on the equipment, the base direct labor rate and base maintenance overhead cost rate for each aircraft were obtained from the Visibility and Management of Operating and Support Costs (VAMOSC) office at the Air Force Logistics Command (AFLC) headquarters. These rates are expressed in dollars per labor hour. The cost data for accomplishing depot-level maintenance on the C-141 Carousel IV navigation units after the warranty expired was collected at the Aerospace Guidance and Metrology Center (AGMC) at Newark Air Force Station, Ohio.

#### Data Analysis Plan

AN/ARN-118 TACAN Units. To determine the reliability of warranted and non-warranted TACAN receiver-transmitter units on F-15 aircraft, a mean-time-between-failure (MTBF) value was determined for the AN/ARN-111 and AN/ARN-118 RTU. This MTBF value was calculated by summing the monthly aircraft operating hours and dividing by the sum of all inherent (type-1) failures experienced during the period of analysis.

To determine the man-hour resources needed to maintain the respective TACAN units, the total number of maintenance manhours expended on each unit was divided by the total number of aircraft operating hours. This resulted in an average maintenance man-hour per flight hour value (MMH/Flt Hr) for each TACAN unit.

To determine the respective operating hours for each type of TACAN unit, a ratio was derived by dividing the average number of ARN-118 equipped F-15 aircraft by the average number of aircraft in the entire F-15 fleet. This was done for each six-month period within the total analysis time frame. For example, between January and June 1980, the average number of ARN-118 equipped F-15 aircraft was 170 out of a total number 446 F-15 aircraft. This results in a ratio of 0.381 or 38.1 percent of the F-15 aircraft were equipped with the ARN-118 TACAN unit. This also meant that 61.9 percent of the F-15 aircraft were equipped with ARN-111 TACAN units during that six-month period. The operating hours for each type of TACAN unit were then calculated by multiplying the F-15 fleet operating hours by the respective ratio.

To determine the cost effectiveness of the warranted ARN-118 TACAN unit versus the non-warranted ARN-111 TACAN unit, the difference in maintenance man-hours per flight hour was calculated. This value was then multiplied by the total aircraft flight hours accumulated by ARN-111 equipped F-15 aircraft from January 1977 to June 1985. This product represents the maintenance man-hour savings if the first 276 F-15 aircraft would have been equipped with the warranted ARN-118 TACAN units instead of the ARN-111. To place a dollar figure on this savings, the sum of the base direct labor rate and the base maintenance overhead cost rate was multiplied by the maintenance man-hour savings. This

dollar savings was then compared to the cost of placing these 276 ARN-118 units under RIW.

Carousel IV Inertial Navigation Unit. To determine the reliability of the INU before and after the warranty expired, two mean-time-between failure (MTBF) values were calculated. The first value was calculated by summing the monthly aircraft operating hours during the warranty period and dividing by the sum of all the inherent (type-1) failures experienced during the same period. The second MTBF value was calculated in the same manner using operating hours and inherent failures accumulated after the warranty period (from March 1981 to June 1985).

To determine the man-hour resources needed to maintain the Carousel IV INU, an average total maintenance man-hour per flight hour value was calculated for the time period before and after the warranty expired. These two values were also separated into "off-equipment" and "on-equipment" maintenance man-hours per flight hour. Off-equipment maintenance man-hours are expended while accomplishing shop repairs away from the flight line. On-equipment maintenance man-hours are expended while doing remove and replace maintenance actions on the aircraft. The method for calculating these values is the same method used in calculating the TACAN units' maintenance manhours per flight hour described in the preceding section.

To determine the cost effectiveness of the RIW on the Carousel IV INU, the off-equipment man-hour per flight hour

value during the warranty period was subtracted from the off-equipment man-hour per flight hour value after the warranty expired. This difference represents the increase in maintenance man-hours per flight hour experienced after the warranty period ended. Off-equipment maintenance man-hours were selected for comparison purposes because the contractor is responsible for the majority of the off-equipment maintenance actions during the warranty period, and Air Force maintenance technicians assume this responsibility after the warranty expires. However, the Air Force technicians perform all of the on-equipment maintenance before and after the warranty expires. The increase in off-equipment maintenance man-hours per flight hour after the warranty expired represents the amount of maintenance Air Force technicians would have expended repairing faulty inertial navigation units in intermediate repair shops. To calculate the total number of these off-equipment maintenance man-hours avoided by the Air Force during the warranty period, this increase was multiplied by the total number of flight hours accumulated before the warranty expired. A dollar value was then assigned to these avoided maintenance man-hours by multiplying them by the sum of the base direct labor rate and the base maintenance overhead cost rate for C-141 maintenance. The cost of depot-level maintenance performed at the Aerospace Guidance and Metrology Center was then added to this base-level man-hour cost. This total dollar figure

was then compared to the cost of placing the 544 inertial navigation units under warranty.

#### Assumptions and Limitations

In this research project, several assumptions were made as part of the data analysis. The first assumption was that the two types of TACAN units were of similar technology and operated under virtually identical mission and environmental stress conditions. It was also assumed that a given proportion of F-15 aircraft equipped with one type of TACAN unit would accumulate that proportion of the total flight hours. For example, if 25 percent of the F-15 fleet were equipped with ARN-118 TACAN units, then those aircraft would log 25 percent of the fleet flight hours. It is further assumed that the difference in reliability between the two units is due primarily to the influence of the RIW.

The fourth assumption was that the B06 report in the maintenance data collection system accurately portray the number of failures, maintenance man-hours, and aircraft flight hours associated with each weapon system and its associated components. It is further assumed that the base direct labor rate and the base maintenance overhead cost rate for each aircraft gives the true cost of each maintenance man-hour expended by Air Force maintenance technicians.

The final assumption deals with the Carousel IV INU. It was assumed that the increased man-hour rate experienced after the warranty represents the rate of maintenance manhours that would have been expended if no warranty was in effect.

This research project was limited to failure and maintenance man-hour data only. The data was not available on savings due to decreased support equipment requirements, transportation costs, and reduced training and provisioning costs associated with warranted equipment.



### III. Findings

#### Introduction

Chapter III presents the findings of the data analysis outlined in Chapter II. This chapter includes a descriptive tabular analysis of the results of the reliability, man-hour per flight hour rates, and cost data.

#### F-15 TACAN Units

The reliability of the two TACAN units was calculated as outlined in Chapter II. Table II lists the mean-time-between-failure values for each of the F-15 TACAN units for each six-month time period. For a graphical comparison of the relative reliability levels, the MTBF values for each type of TACAN unit have been plotted versus time in Figure 1. From 1977 to 1985, the non-warranted ARN-111 TACAN units displayed an average reliability level of 254 hours between each failure. The warranted ARN-118 TACAN units experienced an average reliability level of 805 hours between failure. This reliability rate is over three times the reliability rate of the ARN-111 TACAN units.

The maintenance man-hours expended per flight hour for each type of TACAN unit were calculated for each six-month period by the method described in Chapter II. Table III lists these values for each type of TACAN unit from 1977 to 1985. These values have also been plotted for graphical comparison in Figure 2. During this time period, the warranted ARN-118 TACAN units accumulated 497,304 flight hours

TABLE II  
F-15 TACAN MTBF BY TIME PERIOD

TIME PERIOD	ARN-111 MTBF	ARN-118 MTBF
Jan-Jun 1977	208.2	-
Jul-Dec 1977	247.7	-
Jan-Jun 1978	327.9	-
Jul-Dec 1978	257.5	651.5
Jan-Jun 1979	319.1	663.2
Jul-Dec 1979	320.8	692.5
Jan-Jun 1980	271.5	766.1
Jul-Dec 1980	334.8	1,021.3
Jan-Jun 1981	302.6	1,022.3
Jul-Dec 1981	211.8	975.8
Jan-Jun 1982	324.3	751.0
Jul-Dec 1982	228.6	753.3
Jan-Jun 1983	198.1	869.0
Jul-Dec 1983	234.9	899.2
Jan-Jun 1984	262.2	838.0
Jul-Dec 1984	207.3	728.0
Jan-Jun 1985	168.4	689.8

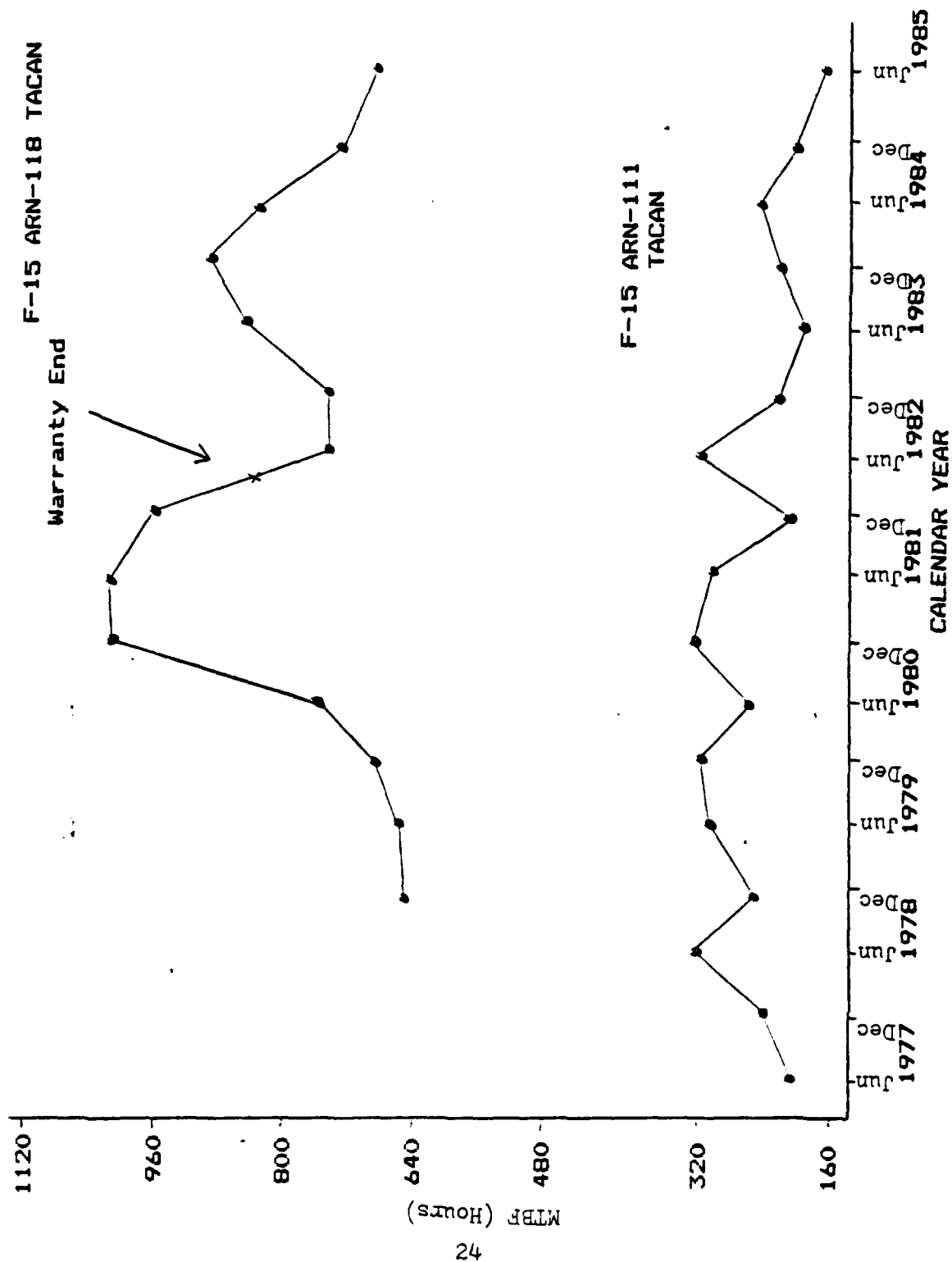


Figure 1. MTBF Comparison of F-15 TACAN RTU

TABLE III

## F-15 TACAN MAINTENANCE MAN-HOURS

PER 1000 FLIGHT HOURS BY TIME PERIOD

Time Period	ARN-111 MMH/1000 Flt Hr	ARN-118 MMH/1000 Flt Hr
Jan-Jun 1977	137.63	-
Jul-Dec 1977	91.33	-
Jan-Jun 1978	81.21	-
Jul-Dec 1978	85.71	50.27
Jan-Jun 1979	83.56	31.88
Jul-Dec 1979	94.20	29.60
Jan-Jun 1980	113.31	31.23
Jul-Dec 1980	88.10	23.13
Jan-Jun 1981	125.75	17.87
Jul-Dec 1981	148.64	21.11
Jan-Jun 1982	134.22	27.96
Jul-Dec 1982	120.48	28.33
Jan-Jun 1983	135.95	30.36
Jul-Dec 1983	124.96	32.73
Jan-Jun 1984	100.91	33.96
Jul-Dec 1984	91.57	31.06
Jan-Jun 1985	123.56	27.51

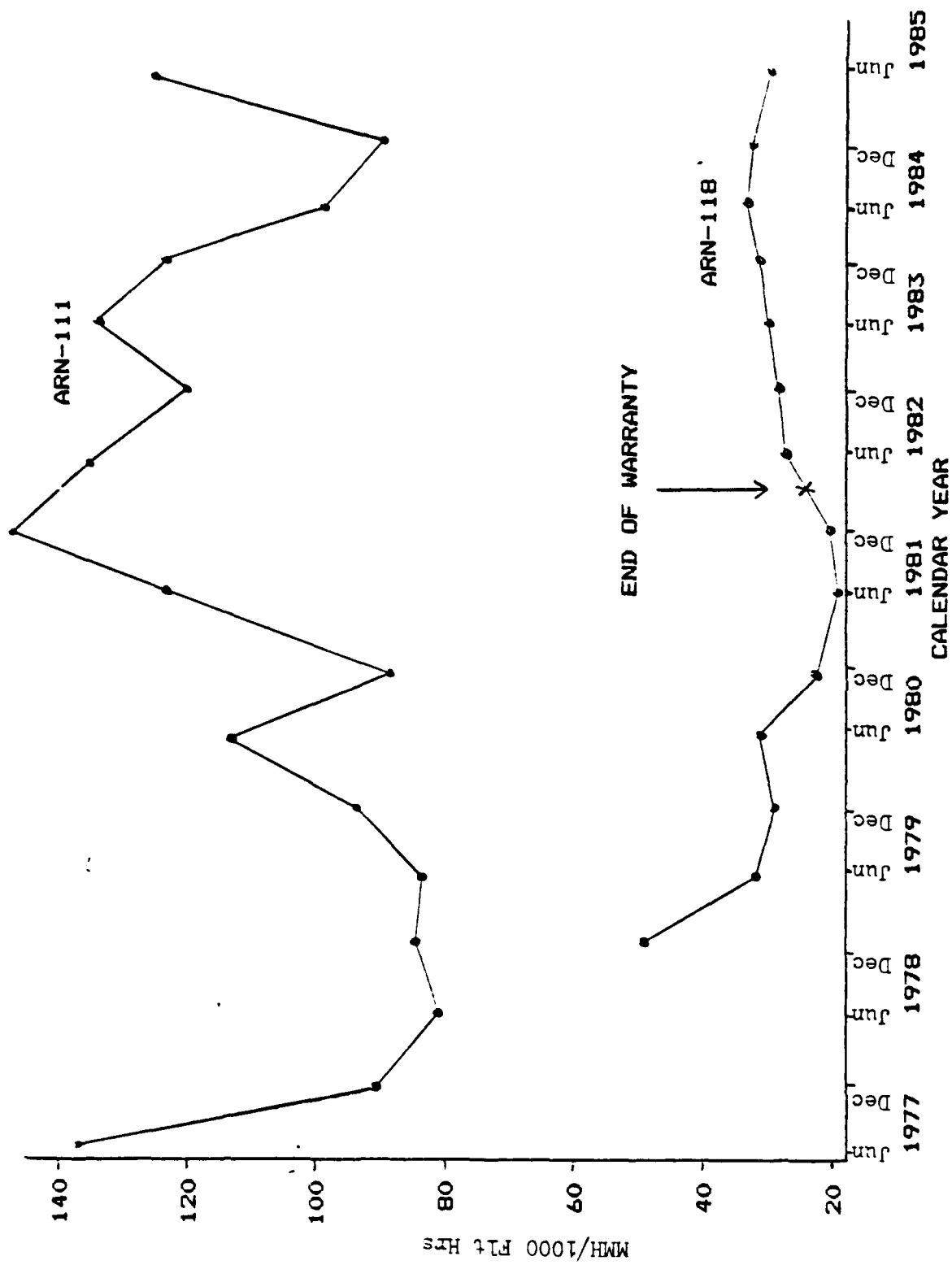


Figure 2. F-15 ARN-118 vs ARN-111 MMH/1000 Flt Hr Comparison

and required 14,254 base level maintenance man-hours to repair and service these units. These figures result in an average maintenance man-hour per flight hour (MMH/Flt Hr) value of 0.02866, or 28.66 maintenance man-hours per 1000 flight hours.

From 1977 to 1985, the ARN-111 TACAN units accumulated 513,640 flight hours and required 52,232 base level maintenance man-hours to repair and service these units. These figures result in an average maintenance man-hour per flight hour value of 0.10948, or 109.48 maintenance man-hours per 1000 flight hours. This rate is well over three times the maintenance man-hour rate for the warranted ARN-118.

As outlined in Chapter II, a simple cost analysis was performed to determine the cost effectiveness of the ARN-118 versus the ARN-111 TACAN units. The difference between the two maintenance man-hour rates is 0.08082 man-hours per flight hour. This rate was then multiplied by the total flight hours accumulated by the 276 F-15 aircraft equipped with the ARN-111 TACAN units during the analysis time frame. The resulting product of 41,512 man-hours represents the man-hour savings if those aircraft would have been equipped with the warranted ARN-118 TACAN units. To place a dollar value on this reduction, the sum of the base direct labor rate and the base maintenance overhead cost rate (\$26.80 per hour) was multiplied by the man-hour savings of 41,512 man-hours yielding a savings of \$1,112,521. This figure was then compared to the cost of placing these 276 ARN-118 units under the RIW.

The cost of the warranty was \$971 for each ARN-118 TACAN receiver-transmitter (RTU). Multiplying this figure by the number of required units yields a final RIW cost of \$267,996. The man-hour savings of \$1,112,521 is \$844,525 more than the associated cost of the RIW.

#### Carousel IV Inertial Navigation Unit

The reliability of the Carousel IV INU was calculated using the method outlined in Chapter II. Table IV lists the mean-time-between-failure values (expressed in hours) for each six-month period before and after the RIW expired at the beginning of March 1981. For a graphical representation of the reliability over time, the MTBF values for each six month period have been plotted in Figure 3. During the warranty period, the Carousel IV inertial navigation units logged 1,662,362 flight hours aboard C-141 aircraft. During this time, these units experienced 1682 inherent (type-1) failures for an average MTBF of 988.3 hours. After the warranty expired, the inertial navigation units logged 2,537,922 flight hours aboard C-141 aircraft from March 1981 to June 1982. During this time, these units experienced 2,630 inherent (type-1) failures for an average MTBF of 965.0 hours.

The on-equipment and off-equipment maintenance man-hours expended per flight hour were calculated for each six month period by the method described in Chapter II. Table IV lists these values for the entire time period. These values have also been plotted for a graphical comparison.

TABLE IV  
C-141 INU RELIABILITY (MTBF) AND  
MAINTENANCE MAN-HOURS PER 1000 FLIGHT HOURS  
(MMH/1000 FLT HRS)

TIME PERIOD	MTBF (HOURS)	ON-EQUIPMENT MMH/1000 FLT HR	OFF-EQUIPMENT MMH/1000 FLT HR
Jan-Jun 1978	685.9	9.70	0.26
Jul-Dec 1978	844.4	8.85	1.94
Jan-Jun 1979	1006.7	9.46	2.42
Jul-Dec 1979	1044.2	8.30	3.90
Jan-Jun 1980	1219.9	5.74	5.27
Jul 80-Feb 81	1112.0	7.49	5.11
Mar-Dec 1981	1305.9	6.16	35.70
Jan-Jun 1982	1362.8	4.29	35.78
Jul-Dec 1982	1108.0	5.96	46.20
Jan-Jun 1983	877.1	7.81	62.62
Jul-Dec 1983	998.8	7.31	55.36
Jan-Jun 1984	757.4	10.62	62.40
Jul-Dec 1984	816.0	10.49	52.88
Jan-Jun 1985	735.0	9.63	46.84



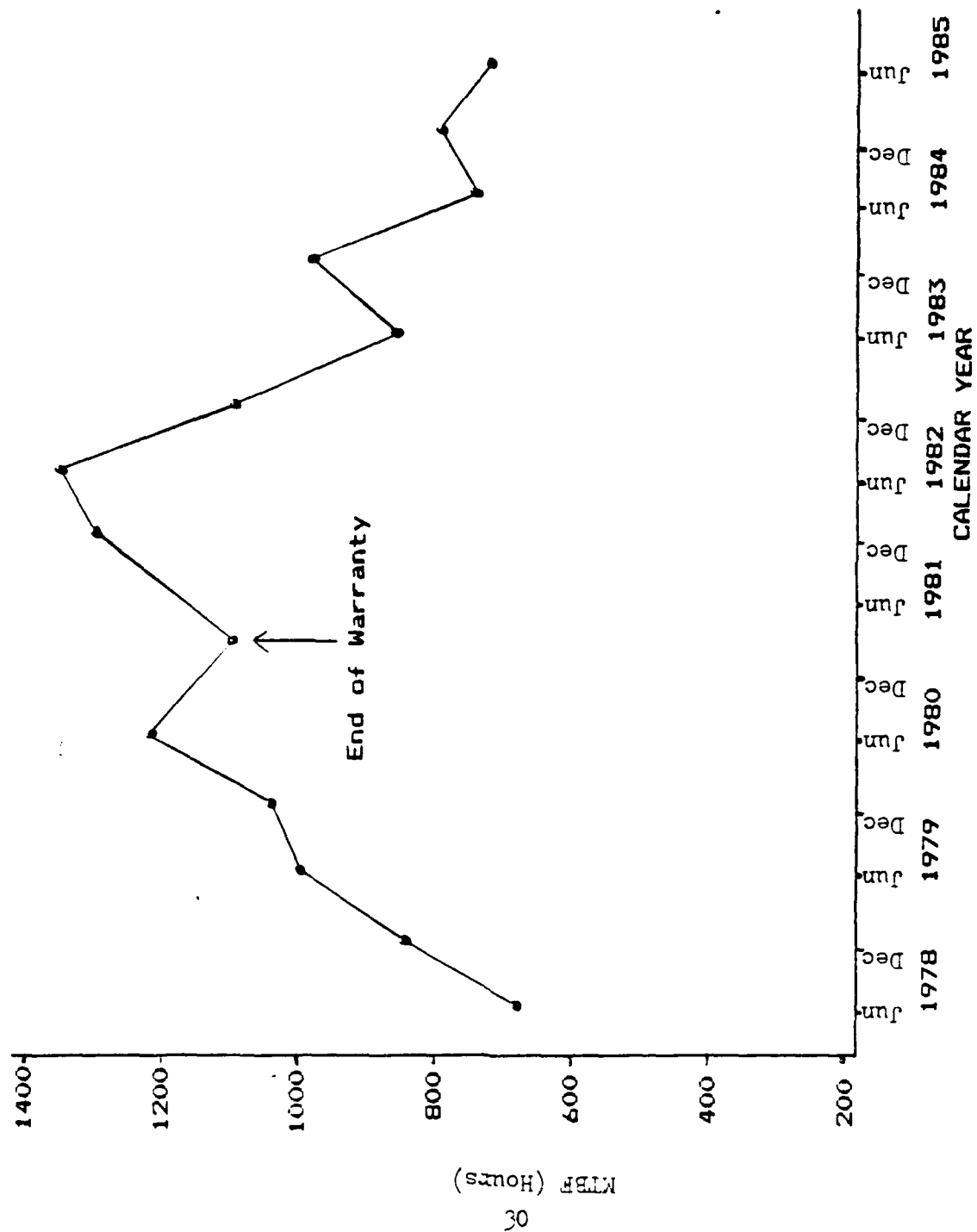


Figure 3. C-141 Carousel IV INU MTBF

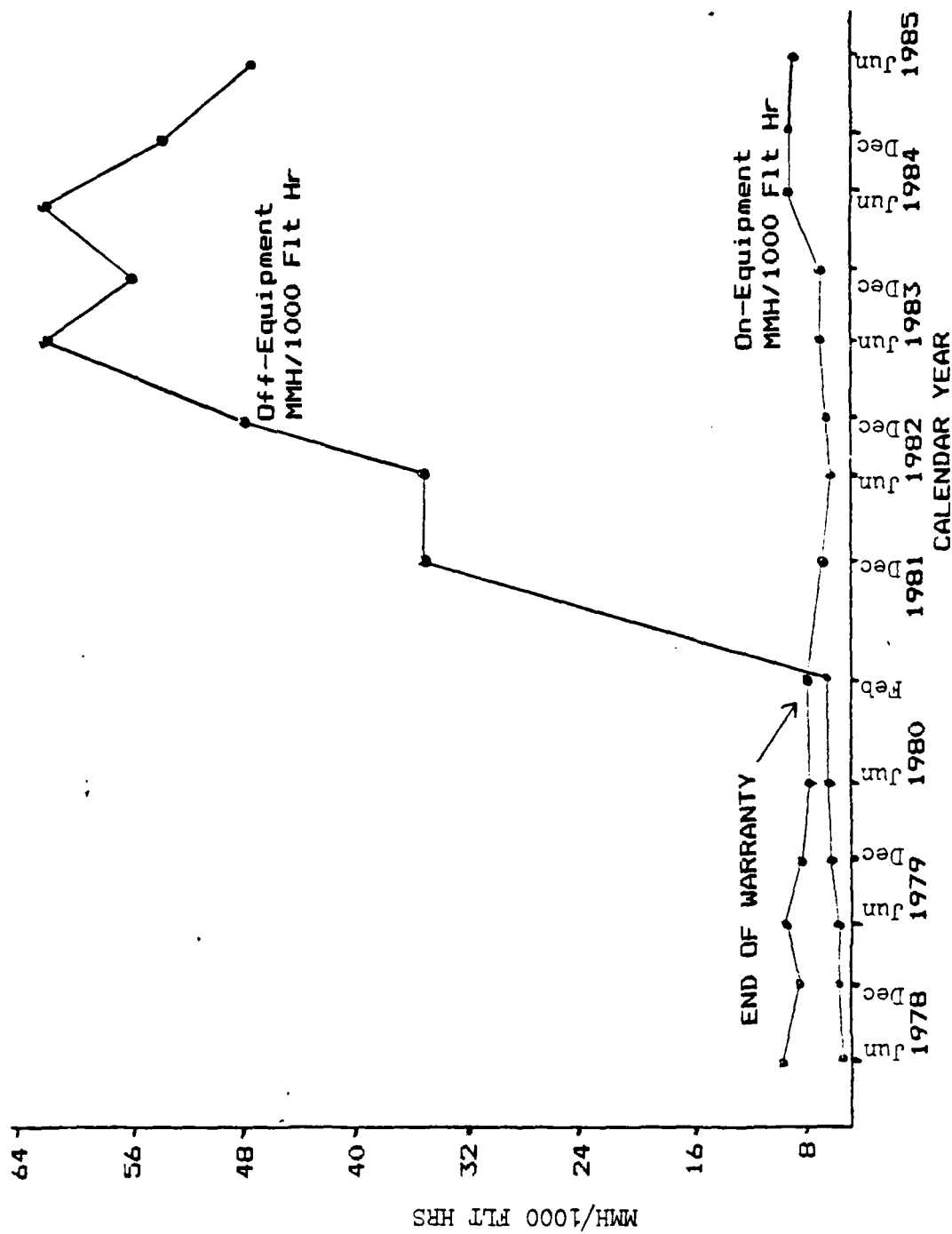


Figure 4. C-141 Carousel IV INU Off vs On Equipment MMH/1000 Flt Hr Comparison

During the warranty period (January 1978 through February 1981), the inertial navigation units required a total of 13,474 on-equipment maintenance man-hours and 5,792 off-equipment maintenance man-hours. These figures were each divided by the total flight hours accumulated during this period (1,662,363 hours). These calculations yield an average on-equipment maintenance man-hour per flight hour (MMH/Flt Hr) value of 0.00811, or 8.11 maintenance man-hours per 1000 flight hours. The off-equipment maintenance man-hour per flight hour value during this period was 0.00348, or 3.48 maintenance man-hours per 1000 flight hours.

After the warranty expired (March 1981 through June 1985), the inertial navigation units required a total of 19,493 on-equipment maintenance man-hours and 123,768 off-equipment maintenance man-hours. These figures were each divided by the 2,537,922 flight hours accumulated during the post-warranty period. These computations yield an average on-equipment MMH/Flt Hr value of 0.00768, or 7.68 maintenance man-hours per 1000 flight hours. The average off-equipment MMH/Flt Hr value during this period was 0.04877 or 48.77 maintenance man-hours per 1000 flight hours.

The increase in off-equipment maintenance man-hours per flight hour was 0.04529 MMH/Flt Hr. This increase represents the added amount of maintenance Air Force technicians would have expended repairing faulty inertial navigation units at base level in the absence of a warranty. To

calculate the total number of off-equipment maintenance man-hours avoided by the Air Force during the warranty period, this increase was multiplied by the 1,662,362 flight hours accumulated before the warranty expired. The resulting product of 75,288 man-hours represents the base-level man-hours saved by placing the equipment under warranty. To place a dollar value on this savings, the sum of the base direct labor rate and the base maintenance overhead cost rate (26.80 per hour) was multiplied by the number of man-hours saved yielding a savings of \$2,055,362. The cost of depot-level maintenance that would have been required and performed at the Aerospace Guidance and Metrology Center (\$1,366,203) was then added to the base-level man-hour cost for a sum of \$3,421,565. This figure was then compared to the cost of placing these 544 Carousel IV inertial navigation units under the RIW.

The cost of the warranty was \$4020 for each Carousel IV inertial navigation unit. Multiplying this value by 544 units yields a final RIW cost of \$2,186,880. The cost of the RIW was \$1,234,685 less than the projected maintenance man-hour costs.

#### IV. Summary, Conclusions, and Recommendations

##### Introduction

The purpose of this chapter is to present the results of this research effort. First, the author will restate the research objectives and questions from Chapter I and summarize the methodology used in this research effort. Second, the author will present several conclusions drawn from the research effort. Finally, recommendations for future follow-on research efforts and research observations relating to the Air Force RIW program will be identified.

##### Research Design Summary

The research objectives and questions identified in Chapter I established the basic framework of this research project and data collection effort. The research objectives were:

1. To determine if completed RIW contracts have been cost effective.
2. To determine if equipment purchased under RIW contracts has shown greater reliability over similar non-warranted equipment.

The specific research questions asked to accomplish these objectives were:

1. What is the additional contract cost of placing equipment under a reliability improvement warranty?

2. Has DOD equipment purchased under reliability improvement warranties shown an increase in field reliability?

3. Do the benefits of increased reliability, such as reduced maintenance man-hours, offset the increased acquisition costs associated with a reliability improvement warranty?

Data was collected from the Maintenance Data Collection (MDC) system and RIW contracts. The author analyzed the data in accordance with the research methodology described in Chapter II. The main points of the research methodology included:

1. Selection of two Air Force RIW programs.
2. Collection of failure data, flying hours, and maintenance man-hours.
3. Collection of warranty cost data from RIW contracts.
4. Calculating reliability data and maintenance man-hour rates, and constructing numerical tables and graphs.
5. Conclusions drawn from the review and interpretation of findings.

### Conclusions

Before accepting the conclusions of this research effort, the reader should review the assumptions and limitations presented in Chapter I. Further, it should be noted that the conclusions apply only to the two systems selected for this research effort. The author did not attempt to

infer or imply the results of this project apply to all the equipment purchased under RIW contracts.

AN/ARN-118 TACAN Units. A summary of the author's conclusions relating to the ARN-118 TACAN units installed in the F-15 aircraft is listed below:

1. The average reliability of the ARN-118 TACAN units was over three times as great as the reliability of the non-warranted ARN-111 TACAN units.

2. The ARN-118 TACAN units showed considerable reliability growth during the warranty period, especially during the time period from January 1979 to January 1981. The non-warranted ARN-111 TACAN units did not show a similar trend.

3. The higher reliability of the ARN-118 TACAN units contributed to a maintenance man-hour rate which was less than one third that of the ARN-111 TACAN units.

4. The reduction in maintenance man-hour costs associated with equipping all F-15 aircraft with warranted ARN-118 TACAN units more than offsets the cost of the RIW. This cost savings is further magnified when the purchase price of the warranted unit (\$6,484) is compared to the purchase price of the more expensive ARN-111 (\$34,500).

5. The ARN-118 TACAN units aboard F-15 aircraft have shown a decline in reliability since the warranty expired in April 1982 with a corresponding rise in maintenance man-hours per flight hour. This decline could be attributed to a combination of the following factors:

- (a) The modifications and engineering change proposals made by the contractor during the warranty to improve reliability were not permanent in nature.
- (b) The units are now older and wear out failures are now occurring at a greater rate.
- (c) The Maintenance Data Collection (MDC) system is capturing more of the failure data than before through increased management attention and technological advances in data automation and transmission.
- (d) The Air Force maintenance technicians repairing these units are not completely diagnosing the failures and thoroughly fixing the entire unit.

Carousel IV Inertial Navigation Unit. A summary list of conclusions relating to the Carousel IV INUs installed on C-141 aircraft is provided below:

1. The inertial navigation units showed considerable reliability growth during the warranty period and for 15 months after the warranty expired. After this 15-month period, the reliability has declined steadily to a level equal to the initial reliability level. This decline could be caused by the same factors which contributed to the decline in reliability of the ARN-118 TACAN units.

2. The average reliability before the warranty was nearly equal to the average reliability after the warranty expired (988.3 hours vs 965.0 hours).



3. The on-equipment MMH/Flt Hr rate during the warranty was nearly equal to the off-equipment MMH/Flt Hr rate after the warranty expired.

4. The off-equipment MMH/Flt Hr rate after the warranty expired was 14 times as great as the rate during the warranty period.

5. The relatively low off-equipment MMH/Flt Hr rate during the warranty period represented a man-hour savings of \$2,055,362.

6. The man-hour costs avoided during the warranty period offset the cost of the RIW by \$1,234,685. Additional savings were also avoided in the areas of training costs, provisioning costs, transportation costs, and support equipment.

#### Recommendations

The effort expended on the development of this thesis has revealed additional areas of potential research that could prove useful in evaluating past, present and future RIW contracts. The results of this effort constitute a first attempt to evaluate base level maintenance man-hour savings due to the improved reliability of equipment procured with RIW. Due to the fact that this study was not able to encompass the entire spectrum of man-hour data or address all of the possible analysis methodologies, further research in this area is warranted. The author suggests the following recommendations for future research in descending order of importance:

1. Replicate this project using the cost savings from reduced packaging and transportation costs, decreased maintenance manpower and skill level requirements, or reduced cost of initial support equipment and spare parts.
2. Replicate this project on other equipment procured with reliability improvement warranties, such as the Standard Inertial Navigation Unit installed on the A-10 aircraft.
3. A parallel research effort should be performed to measure the effectiveness of the Army and Navy's RIW program.
4. Design a research project to develop a standardized management information system or logistics decision support system to aid Air Force RIW management.

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Captain Paul E. Leix was born on 6 March 1953 in Flint, Michigan. He graduated from high school in Flint, Michigan in 1971 and attended the University of Michigan from which he received the degree of Bachelor of Arts in May 1975. In April of 1980 he received a commission in the USAF through the Officer Training School Program. After technical school he was assigned as the Branch Chief of the Maintenance Data Analysis Branch at the Air Force Communications Command Headquarters, Scott AFB, Illinois. He began graduate studies at the School of Systems and Logistics, Air Force Institute of Technology, in May of 1984.

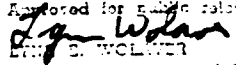
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Reliability Improvement Warranties (RIWs) were implemented by the Air Force in 1974. This marked the beginning of the eight-year RIW trial period. Six major Air Force programs have used RIWs since 1974. The Air Force Director of Contracting and Manufacturing Policy requested that the RIW trial period be ended and that the effectiveness of this program during the trial period be measured. This research project was an attempt to evaluate the costs and benefits associated with two RIWs implemented during this time period. Reliability data and maintenance man-hour values were collected on warranted equipment throughout its history of operation. Similar data was collected on equivalent non-warranted equipment for comparison purposes. The increase in reliability and decrease in expended maintenance man-hours on warranted equipment was also compared to the increase in contract costs associated with the RIW. This study indicated that the RIW was a cost-effective tool in increasing reliability and reducing the number of man-hours required to maintain certain Air Force equipment.

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